Augmented Reality: Dangerous Liaisons or the Best of Both Worlds?

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In 1991, I saw a then top-secret talk by N. Sheridon at Xerox PARC on an extraordinary new technology called 'electronic paper'. Instead of a bulky computer monitor, displays of the future would be the thickness and flexibility of a sheet of paper. The technology is clever: tiny pixel-sized drops of ink, half white and half black, are spread into a thin layer, each surrounded by a miniature pocket of oil. The pixels are bi-stable: under ordinary conditions they do not change direction and act like ordinary ink. Yet when connected to a tiny device, each individual pixel can be rotated at will, making is possible to display text and images with the same control as any computer monitor.

This fundamentally changed my research direction into what is now called augmented reality, with a special interest in augmented paper. Together with my colleagues Wellner and Gold, we edited an special issue of the *Communications of the ACM* in 1993, which was the first collection of articles on the topic. Since then, the field has exploded, with a growing range of new technologies and use settings. Although Sheridon's technology, and similar ones such as Jacobson's electronic ink at the MIT Media Lab, are only just now reaching the stage of being demonstrable, it was clear that this augmented paper would fundamentally change the notion of what it meant to interact with a computer.

Although I am interested in new technologies, my research approach is centered around the future uses of these new technologies. In particular, I am interested in situations in which people have an existing, very successful use of a paper artifact, but a clear need for computer support as well. I have investigated a number of situations in which the initial strategy has been to create a computer replacement for the paper artifact. For example, it was often predicted in the 1970s and early 1980s that the "paperless office", with a computer, would replace the office as we know it and paper would disappear. As we know, the computer has proliferate, but so has paper. The computer has directly affected today's offices, not by getting rid of paper, but by significantly increasing the quantity of it. But today's users face a new challenge: how do they juggle this mass of paper and the growing number of on-line files?

This problem is replicated in many situations: In each case, the naive assumption is that the introduction of the computer will replace existing paper artifacts. Yet more often than not, the result is more complex: Users come to rely on the new features offered by the computer, but also maintain the paper artifact. They must thus manage two kinds of documents: those embodied as physical paper and those entirely on-line, with a new problem of how to manage the link between the two.

My research has led me to investigate a number of such situations. In each case, the emphasis is not been on the details of the new technology per se, but on exploring the design space of how these technologies might work in the future. I have concentrated on the problem of augmenting paper, with a special interest in situations in which people have successfully used a particular paper artifact for years, but see a clear benefit to adding the power of a computer or computer network. In such cases, although the software is designed to completely replace the paper artifact, users often create new work practices involving both on-line and paper documents. What is it about the physical characteristics of the users' interaction with paper that makes it so powerful? How can we design systems that take advantage of both the physical and virtual characteristics of paper?

My research approach always begins with the study of an existing mixed-use setting. The first project was based on my work with video producers during the development of multimedia productions. Although on-line video editing capabilities were available, these producers continued to use paper storyboards to sketch and work through the design of a video production. We decided to link the off-line and on-line storyboards in a system called Video Mosaic (Mackay et al., 1993, Mackay and Pagani, 1994). In this setting, the computer offered easy access to dynamic information, whereas the paper artifacts offered significantly greater capabilities for laying out temporal information in space. We developed and experimented with several versions of Video Mosaic, using Digital Desk technology from EuroPARC. The user could use paper storyboards to control an on-line video editing system and a camera could capture annotations and changes in position made by the user, allowing the user an easy transition between the paper and the on-line elements of the storyboard. (See Burr & Søndergaard, 2000, in this proceedings for a similar application.) Of course, the technology at the time was bulky, but we envisioned a lightweight version that would be based on electronic paper.

The second major project, Ariel, involved a three-year study of Danish engineering supervisors working on the development of the Great Belt bridge in Denmark

(Mackay et al., 1996, Mackay, 1998). In this setting, all of the engineers had computers on their desks, but never used them to read paper engineering drawings. They were rarely in their offices: the job entailed constant movement from on-shore and off-shore construction site. They also preferred to handle a small number of currently-relevant paper documents rather than searching for them on-line. We developed a series of prototypes that explored how to capture and share hand-written annotations on the paper drawings, using Digital Desk technology to capture annotations and media space technology (Mackay, 1999) to support live and multimedia communication.

The third project, Caméléon, involved a much smaller paper artifact with a much shorter lifespan: paper flight strips used by air traffic controllers. Most attempts to replace paper flight strips have failed and controllers continue to use the paper strips, which have evolved gradually over the past 50 years. We began with a four-month intensive study of a group of en route air traffic controllers at the Paris Athis Mons control center (Mackay, 2000). We then engaged in a year-long participatory design project to create working prototypes of an augmented paper strip, which allowed controllers to use the paper strips as before, but also use them as an interface to the RADAR and other on-line systems (Mackay et al., 1998).

Our current project involves laboratory notebooks at the Institut Pasteur in Paris. Although biologists use computer-technology as an integral part of their work, they also continue to use paper notebooks. This is for both practical and legal reasons: patents and attribution of discoveries are based on who conducted which experiment first. As before, we began with studies of biologists using their laboratory notebooks, followed by participatory design sessions in which we created two variations of an augmented laboratory notebook. The prototypes help biologists track both information within paper documents and from paper to electronic documents (and other media: Biologists must also deal with biological samples and relationships to world-wide databases, such as in the Human Genome project).

Studying real users and designing prototypes for use in real-world settings has forced me to think about a potential problem with augmented paper or any augmented reality application. Initially, AR seems a wonderful solution to a tricky problem, retaining all the advantages of our abilities as human beings to deal with physical objects, while benefiting from the computer.

But who controls the link between the two? What happens when the links break down? What happens if the augmentation of the physical paper creates confusion in a previously-clear situation? Physical artifacts are useful precisely because they are so predictable. They afford certain types of interaction, and we as human beings evolve our use of them accordingly. In contrast, on-line systems are notoriously difficult to understand: other people, rather than the laws of nature, dictate how they work. When we create augmented artifacts, we need to be sure that we are enhancing, not confusing, users' existing understandings of the physical object. Combining the on-line and off-line capabilities is not always benign. We must also consider users' expectations of augmented technologies. How do can users find out when and how the links between the physical and electronic have broken down? How can the user fix it? Particularly in safety-critical situations, if augmentation disappears, the remaining physical object must still "work".

Finally, we should seriously consider who is in control of the link between the on-line and off-line documents. The temptation is to let software engineers control these links, since they are the ones technically responsible for creating them. But another strategy is to explicitly give the control to the users, allowing them to define and more importantly, continue to evolve, the relationship between the physical and virtual documents. The strategy of examining real-world use in the light of new augmented reality technology provides a way of identifying and addressing these potentially dangerous liaisons between the physical and virtual, giving augmented reality the chance to really act as the best of both worlds.

REFERENCES

Mackay, W.E., Velay, G., Carter, K., Ma, C., & Pagani, D. (1993) Augmenting Reality: Adding Computational Dimensions to Paper. In Wellner, P., Mackay, W. & Gold, R. (Eds.) Computer-Augmented Environ-ments: Back to the Real World. Special issue of *Communications of the ACM*, 36 (7).

Mackay, W.E. & Pagani, D. (1994). Video Mosaic: Laying out time in a physical space. In *Proceedings of Multimedia '94* . San Francisco, CA: ACM.

Mackay, W.E., Pagani D.S., Faber L., Inwood B., Launiainen P., Brenta L., and Pouzol V. (1995). Ariel: Augmenting Paper Engineering Drawings. Videotape Presented at CHI '95.

Mackay, W., Fayard, A-L, Frobert, L. & Médini, L. (1998) Reinventing the Familiar: Exploring an Augmented Reality Design Space for Air Traffic Control. In *Proceedings of ACM CHI '98 Human Factors in Computing Systems.* Los Angeles, California: ACM/SIGCHI.

Mackay, W.E. (May, 1998) Augmented Reality: linking real and virtual worlds. *Proceedings of ACM AVI '98, Conference on Advanced Visual Interfaces*. Bari, Italy: ACM. Keynote address.

Mackay, W.E. (1999) Media Spaces: Environments for multimedia interaction. In M. Beaudouin-Lafon (Ed.), *Computer-Supported Cooperative Work, Trends in Software Series*. Chichester:Wiley and Sons, pp.55-82.

Mackay, W.E. & Fayard, A-L. (1999) Designing Interactive Paper: Lessons from three Augmented Reality Projects. In Proceedings of IWAR'98, International Workshop on Augmented Reality. Natick, MA: A K Peters, Ltd.

Mackay, W.E. (2000) Is Paper Safer? Augmenting Paper Flight Strips to Support Air Traffic Control. To appean in ACM/TOCHI Transactions on Computer-Human Interaction.